इंटरनेट मानक

Disclosure to Promote the Right To Information

Whereas the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

"जानने का अधिकार, जीने का अधिकार"
Mazdoor Kisan Shakti Sangathan
"The Right to Information, The Right to Live"

"पुराने को छोड नये के तरफ"
Jawaharlal Nehru
"Step Out From the Old to the New"

IS 4540 (1968): Monocrystalline semiconductor rectifier assemblies and equipment [ETD 31: Power Electronics]

"ज्ञान से एक नये भारत का निर्माण"
Satyanarayan Gangaram Pitroda
"Invent a New India Using Knowledge"

Act Number 22 of 2005
The Indian Parliament
RIGHT TO INFORMATION

Made Available By
Public.Resource.Org

"ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है"
Bhartṛhari—Nītiśatakam
"Knowledge is such a treasure which cannot be stolen"

BLANK PAGE

BRUTUM FULMEN

IGNORANTIA JURIS NON EXCUSAT

PROTECTED BY COPYRIGHT

IS : 4540 - 1968

(Reaffirmed 2001)

Indian Standard
SPECIFICATION FOR MONOCRYSTALLINE SEMICONDUCTOR RECTIFIER ASSEMBLIES AND EQUIPMENT

(Fourth Reprint OCTOBER 1997)

UDC 621.382.2 : 621.314.6

© *Copyright* 1969

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 8

May 1969

Indian Standard
SPECIFICATION FOR MONOCRYSTALLINE SEMICONDUCTOR RECTIFIER ASSEMBLIES AND EQUIPMENT

Power Convertors Sectional Committee, ETDC 31

Chairman	*Representing*
SHRI J. D. MALHOTRA	Railway Board (Ministry of Railways)
Members	
SHRI S. K. KANJILAL (*Alternate* to Shri J. D. Malhotra)	
ADDITIONAL CHIEF ENGINEER	Directorate General of Posts & Telegraphs (Department of Communications)
DIRECTOR OF TELEGRAPHS (L) (*Alternate*)	
DIVISIONAL ENGINEER TELEGRAPHS (P) (*Alternate*)	
SHRI P. K. BANERJEE	Hindustan Steel Ltd, Ranchi
SHRI S. P. PROTHIA (*Alternate*)	
SHRI S. BANERJEE	E. Ruttonsha Private Ltd, Bombay
SHRI I. M. RAO (*Alternate*)	
SHRI M. G. BHAT	Automatic Electric Private Ltd, Bombay
SHRI R. R. KARANDIKAR (*Alternate*)	
SHRI R. K. BOSE	The Calcutta Electric Supply Corporation Ltd, Calcutta
SHRI K. R. DASGUPTA (*Alternate*)	
SHRI P. CHAWLA	The Fertilizer Corporation of India Ltd, Nangal
SHRI S. K. MALIK (*Alternate*)	
SHRI H. C. GHULATI	Directorate General of Supplies & Disposals (Ministry of Supply, Technical Development & Material Planning)
SHRI R. K. TADKOD (*Alternate*)	
SHRI HARNAM SINGH	Chief Inspectorate of Electronics (Ministry of Defence), Bangalore
SHRI T. K. SHANKARANARAYANA RAO (*Alternate*)	
SHRI S. M. KHER	Hind Rectifiers Ltd, Bombay
SHRI S. M. MANE (*Alternate*)	
SHRI R. MANMOHAN	Elvoc Private Ltd, Calcutta
DR J. K. CHOUDHURY (*Alternate*)	
SHRI V. R. NARASIMHAN	Central Water & Power Commission (Power Wing)
SHRI N. W. NOTANI	Asia Electric Company, Calcutta
SHRI R. C. KESWANI (*Alternate*)	
SHRI P. V. RAO	Indian Telephone Industries Ltd, Bangalore

(*Continued on page* 2)

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

(*Continued from page* 1)

Members	*Representing*
Shri D. N. Sen	Martin Burn Ltd, Calcutta
Shri J. Chatterjee (*Alternate*)	
Shri M. T. Shivdasani	Kaycee Industries Ltd, Bombay
Shri N. J. Pherwani (*Alternate*)	
Shri M. S. Srinivasa Murthy	Heavy Electricals (India) Ltd, Bhopal
Shri M. S. Surana	Hindustan Aluminium Corporation Ltd, Renukoot
Shri Vinod Chandra	Siemens India Ltd, Bombay
Shri P. P. S. Anand (*Alternate*)	
Shri Y. S. Venkateswaran, Director (Elec tech)	Director General, ISI (*Ex-officio Member*)

Secretary

Shri R. C. Jain
Assistant Director (Elec tech), ISI

Indian Standard

SPECIFICATION FOR MONOCRYSTALLINE SEMICONDUCTOR RECTIFIER ASSEMBLIES AND EQUIPMENT

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 7 February 1968, after the draft finalized by the Power Converters Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard has been prepared with the object of laying down the performance requirements and testing procedures for the rectifier assemblies and equipment making use of monocrystalline semiconductor cells and stacks. These cells and stacks have been covered by IS : 3895-1966*.

0.3 In the preparation of this standard, assistance has been derived from the following:

IEC Publication No. 146-1963 Monocrystalline semiconductor rectifier cells, stacks, assemblies and equipments. International Electrotechnical Commission.

Draft British Standard Specification for Monocrystalline semiconductor rectifiers for industrial power purposes including cells, stacks, assemblies and equipments — Document No. 66/9222. British Standards Institution.

0.4 This standard contains clauses which call for agreement between the purchaser and the supplier or which permit the purchaser to use his option for selection to suit his requirements or which require the purchaser to supply certain technical information at the time of placing orders. The relevant clauses are **2.1.3.6**, **4.1**, **4.2**, **4.3**, **6.2.1**, **6.3.1.3**, **6.3.2.1**, **6.3.3.1**, **6.4.4.2**, **6.4.5**, **6.5.1.3** and **6.8.8**.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

---

*Specification for monocrystalline semiconductor rectifier cells and stacks.

†Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard applies to monocrystalline rectifier assemblies and equipment for supplying dc power from ac sources at frequencies up to 2 000 c/s and for dc power for voltages not exceeding 5 000 V.

1.1.1 In so far as it is applicable this standard relates also to controlled semiconductor devices having trigger characteristics. More detailed treatment of controlled semiconductor devices (that is, thyristors) would be dealt with in a separate standard.

1.2 It does not apply to telecommunication rectifiers other than those for power supplied to such apparatus, nor to rectifiers used as auxiliaries to measuring instruments. Further, it does not apply to rectifiers based on polycrystalline semiconductor materials.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply in addition to the terms already defined in IS : 3895-1966*.

2.1 Ratings

2.1.1 *Rating* — A statement of the capabilities under the service conditions of this standard, as assigned to the equipment by the manufacturer.

2.1.2 *Rectifier Transformer*

2.1.2.1 *Rated frequency* — The frequency at which the rectifier transformer is designed to operate.

2.1.2.2 *Rated voltage of line winding* — The rms voltage between lines on the line side of the transformer, specified as the basis of rating. If the line winding is provided with tappings, the rated voltage of the line winding shall refer to a specified tapping, which is designated as the principal (rated) tapping.

2.1.2.3 *Rated current on line side* — The rms current of the line terminals of the transformer. For polyphase equipment this is to be computed from rated direct current on the basis of rectangular-shaped rectifier arm currents. For single-phase equipment the basis of calculation is to be that of sine wave unless otherwise agreed between the purchaser and the supplier.

NOTE — In the case of polyphase equipment the use of rectangular-shaped rectifier current provides a simple and approximately correct allowance for the effect of harmonic stray losses in the transformer and connections. The reason for not similarly using rectangular-shaped rectifier currents as the basis in the single-phase case is that it may result in a negative allowance for harmonic stray losses.

---

*Specification for monocrystalline semiconductor rectifier cells and stacks.

2.1.2.4 *Rated current on cell side* — The rms current in each terminal of the transformer on the cell side. For polyphase equipment this is to be computed from rated direct current on the basis of rectangular-shaped rectifier arm currents. For single-phase equipment the basis of calculation is to be agreed between the purchaser and the supplier.

2.1.2.5 *Rated* kVA *of line side winding* — The total apparent power expressed in kVA at the line terminals, at rated frequency, rated line voltage and at rated line current, computed in accordance with **2.1.2.3.**

2.1.3 *Rectifier Assemblies and Equipments*

2.1.3.1 *Rated output* — The product of the rated direct voltage and the rated direct current, which the equipment delivers under the specified duty cycle in the conditions stated in this standard and within the operating limitations assigned to it by the manufacturer.

2.1.3.2 *Rated direct current* — The direct current specified as the basis of rating. It is the arithmetic mean value of the waveform of the direct current which the rectifier equipment or assembly is capable of carrying under the specified duty cycle and service conditions.

2.1.3.3 *Rated direct voltage* — The direct voltage specified as the basis of rating. It is the arithmetic mean value of the voltage between dc terminals of the rectifier equipment or assembly at rated direct current.

2.1.3.4 *Rated current in the middle wire of 3-wire equipment* — The direct current specified as the basis of the out-of balance rating. It is the arithmetic mean value of the direct current which the 3-wire rectifier equipment or assembly is capable of carrying in the middle wire under the specified service conditions. The middle wire may carry its full rated current when the current in the more heavily loaded outer is equal to or less than its rated value.

2.1.3.5 *Rated input voltage* — The rms value of the voltage between lines of the ac circuit from which the equipment or assembly is to operate and on which the declared performance is to be based.

2.1.3.6 *Rated input current* — The rms value of the alternating current drawn from the ac supply at rated direct current. For polyphase equipment this is computed from the rated direct current on the basis of rectangular-shaped rectifier arm currents. For signle-phase equipment the basis of calculation is that agreed between the purchaser and the manufacturer.

2.2 Transformer Windings

2.2.1 *Line Windings* — The windings which are connected to the ac supply.

2.2.2 *Cell Windings* — The windings which are connected to the rectifier cells of a rectifier assembly.

2.3 Equipment Performance

2.3.1 *Conversion Efficiency* — The ratio of the product of the average value of dc voltage and direct current to the input active power on the ac side. (Expressed in this way the maximum efficiency for the single-phase bridge connection on resistance load with sinusoidal supply is 0·81).

2.3.2 *Power Efficiency* — The ratio between the output power (as measured by a wattmeter) on the dc side and the input active power on the ac side.

Note — In cases where the pulse number and the inductance in the dc circuit are both small, the ' Conversion efficiency ' is appreciably less than the ' Power efficiency ' (which corresponds to the losses in the rectifier equipment) by an amount that depends on the character of the load.

In most practical cases, where efficiency is important, this discrepancy is negligible as the pulse number is 6 or more, or there is considerable inductance in the dc circuit.

However the ' Power efficiency ' as defined above avoids these ambiguities as it is practically independent of factors outside the rectifier equipment and always corresponds to the losses in the rectifier equipment. It is for this reason that the term ' efficiency ' in this standard refers to the ' Power efficiency '.

2.3.3 *Total Power Factor* λ

$$\lambda = \frac{\text{Active power}}{\text{Apparent power}}$$

2.3.4 *Power Factor of Fundamental Wave or Displacement Factor* (*Cos* ϕ)

$$\text{Cos } \phi = \frac{\text{Active power of the fundamental wave}}{\text{Apparent power of the fundamental wave}}$$

2.3.5 *Distortion Factor* (v)

$$v = \frac{\lambda}{\cos \phi}$$

2.4 Voltage Regulation

2.4.1 *dc Output Voltage/Current Characteristic* — The relation between the average values of direct voltage and direct current of a rectifier equipment as expressed by a curve, for a given alternating voltage, frequency of supply and for a specified character of load. An example is given in Fig. 1.

2.4.2 *Conventional No-Load Voltage* — The value of direct voltage which would be obtained by extrapolating the dc output voltage/current characteristic back to zero current (*see* Fig. 1).

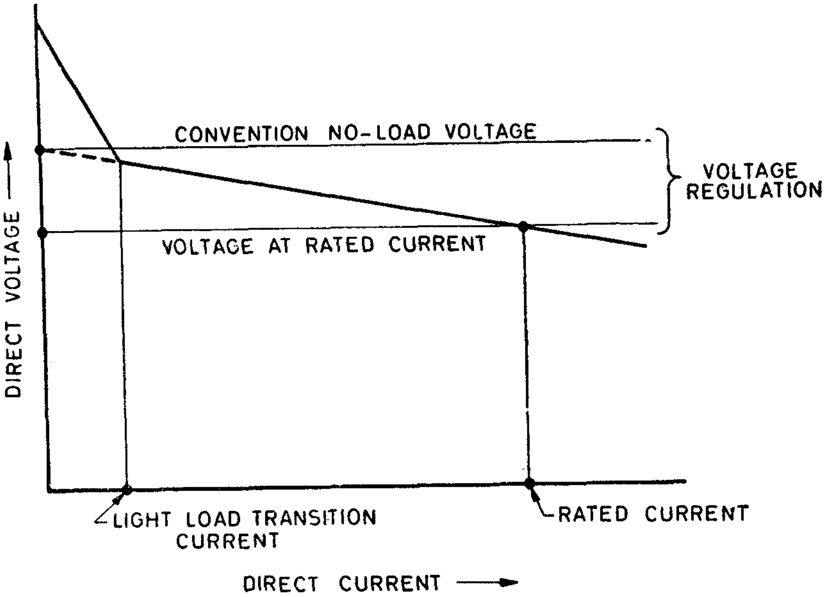


FIG. 1 dc OUTPUT VOLTAGE/CURRENT CHARACTERISTIC

2.4.3 *Ideal No-Load dc Voltage* — The ideal no-load dc voltage of a rectifier assuming no reduction by phase control, no voltage drop in the cells and no voltage rise at small loads. This is obtained from the phase to neutral voltage U_{vo}, the commutating number q and the number of series connected commutating groups, s, or from the voltage between any two plases of the cell winding U_{ψ_o}, and from the angle ψ between these two phases by the formula:

$$U_{dio} = \sqrt{2}\, U_{vo} \cdot \frac{qs}{\pi} \sin\frac{\pi}{q} = \sqrt{2}\; U_{\psi o} \frac{qs}{2\pi} \cdot \frac{\sin\frac{\pi}{q}}{\sin\frac{\psi}{2}}$$

2.4.4 *dc Voltage Regulation* — The difference between the direct voltage at rated current and the conventional no-load voltage (*see* Fig. 1) expressed in volts, when the rms voltage remains constant at the line terminals of the rectifier equipment.

NOTE — The nature of the dc load circuit (for example capacitors, back-emf-load) may affect the voltage regulation and where this is so, special consideration may be required.

2.4.5 *Inherent Voltage Regulation* — The voltage regulation, excluding the effect of ac system impedance and the correcting effect of the automatic voltage regulator, if used.

2.4.6 *Total Voltage Regulation* — The voltage regulation including the effect of the ac system impedance where specified but excluding the correcting effect of the automatic voltage regulators, if used.

2.4.7 *Corrected Voltage Regulation* — The voltage regulation when an automatic regulator is used. The influence on dc voltage of other factors than load changes is to be excluded.

2.4.8 *Deviation in Automatic Control* — Half the difference between the highest and lowest values of the dc output voltage, and wirtten with a ± sign. The deviation shall be stated for a specific range of factors which may have influence on this, such as variations in load, input ac voltage, temperature, etc.

2.5 Tests

2.5.1 *Type Tests* — Tests carried out to prove conformity with the requirements of this specification. These are intended to prove the general qualities and design of a given type of monocrystalline rectifier assembly and equipment.

2.5.2 *Routine Tests* — Tests carried out on each monocrystalline rectifier assembly and equipment to check requirements likely to vary during production.

3. INPUT VOLTAGE

3.1 Waveform

3.1.1 The input alternating voltage shall be sinusoidal at the ac terminals of the rectifier equipment, when the equipment is disconnected.

3.1.2 The waveform of the input voltage shall be considered sinusoidal if the largest deviation ($a - b$) in Fig. 2, from the simultaneous value b of the fundamental wave, does not exceed 5 per cent of the peak value c of the fundamental wave, that is

$$(a - b) \leq 0{\cdot}05\, c$$

For 12-phase rectifier without automatic asymmetry correction, this limit shall be reduced to 2·5 percent, that is

$$(d - b) \leq 0{\cdot}025\, c$$

3.2 ac System Impedance — For rectifier equipment when the effect of ac system impedance may be significant clauses **6.3.4, 6.3.5, 6.3.6** and **6.3.7** relating to the influence of the ac system impedance, shall apply.

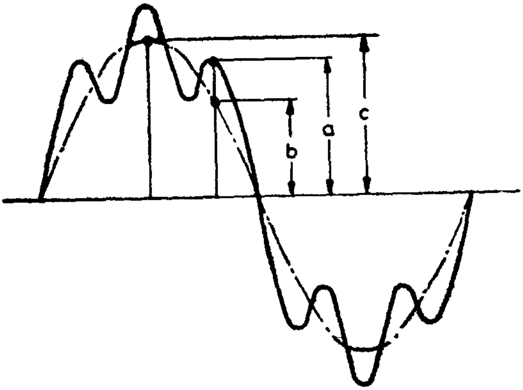


FIG. 2 WAVEFORM FOR ALTERNATING VOLTAGE

3.3 Symmetry (For Polyphase System)

3.3.1 In the case of polyphase systems the input voltage shall be symmetrical.

3.3.2 The voltage shall be considered symmetrical, if neither the negative sequence nor the zero sequence component exceeds 5 percent of the positive sequence component.

3.3.3 If a polyphase system is not perfectly symmetrical but is within the limits of **3.3.2**, the arithmetic mean value of all phase-to-phase voltages shall be taken as the line voltage.

3.4 Voltage and Frequency Variations

3.4.1 Assemblies and equipment shall be capable of temporary operation with an input voltage up to 110 percent of rated input voltage and a frequency not less than 95 percent of rated frequency, provided that a decrease in frequency does not coincide with an increase in voltage. When ac voltage between 100 and 110 percent of rated values is applied, rated current or rated power or both shall be not exceeded.

NOTE — Variations in the ac supply voltage, within the above limits, will give rise to a similar variation in the dc output voltage, unless compensating measures are taken.

4. SERVICE AND INSTALLATION CONDITIONS

4.1 Normal and unusual service and installation conditions are given in Appendix A. The unusual conditions given in Appendix A, if existing, shall be subject to agreement between the purchaser and the supplier.

4.2 Cooling Medium Temperatures

4.2.1 The temperatures specified for the rectifier stacks and for the rectifier transformers may differ from one another. The values of cooling medium temperature relating to transformer are given in IS : 2026-1962* and those relating to the cells and stacks are given below:

a) In every case, the ambient temperature or cooling medium temperature shall be specified by the purchaser or, failing this, by the manufacturer in his tender. It is in the interest of the purchaser to specify for each as low a maximum temperature as the local climatic conditions will permit. These temperatures shall preferably be specified in 5 degree increments and those commonly used are listed below:

a) For air — maximum 25°, 30°, 35°, 40°, 45°C etc.

b) For water — maximum 15°, 20°, 25°, 30°, 35°C etc.

NOTE 1 — If the cooling air used is not the same as the ambient air, separate temperature limits shall be specified for each.

NOTE 2 — If the cooling air is the same as the ambient air, the same limits shall apply to both.

NOTE 3 — For various cooling methods and temperatures definitions reference may be made to **2.4** of IS : 3895-1966†.

4.3 Character of Load — As it may effect the performance characteristics of a rectifier equipment, the character of the load shall always be specified, for example resistive load, inductive load, counter emf load, regenerative load, etc.

5. TRANSFORMERS AND REACTORS

5.1 General

5.1.1 This standard covers only those characteristics in which rectifier transformers differ from ordinary power transformers. In other respects the transformers shall conform to IS : 2026-1962*, as far as they are not in contradiction with the requirements of this standard.

NOTE — It should be borne in mind, that a rectifier transformer operates with non-sinusoidal current waveshape. In single-way connection the current in each cell winding contains a dc component which calls for special attention in design and testing. In some cases special design is necessary when external short circuit and cell failures would cause abnormal stress.

5.1.2 The rating of the rectifier transformers shall correspond to the rating of the associated rectifiers assembly.

5.2 Temperature Rise — The limits of temperature rise shall be in accordance with Table 3 and with the corrections given in Appendix B.

---

*Specification for power transformers.

†Specification for monocrystalline semiconductor rectifier cells and stacks.

The limits given in Table 3 relate to the service conditions which are specified in IS : 2026-1962*.

5.3 Marking

5.3.1 Every transformer and reactor, unless forming part of a rectifier equipment delivered as a mechanically assembled unit, shall bear the words ' Rectifier Transformer ' or ' Reactor '. It shall bear a rating plate which shall give in clear and durable characters the following information in addition to the manufacturer's name, serial number, year of manufacture and designation of type:

a) Rated dc voltage;
b) Rated direct current;
c) Rating class, if any (**6.2**);
d) Number of phases *m* : line side/cell;
e) Rated frequency;
f) Resistive dc voltage drop (**6.3.3.2**);
g) Inductive dc voltage drop (**6.3.3.4**);
h) Weight of core and winding assembly in kg;
j) Weight of the tank;
k) Volume or weight of liquid;
m) Connection;
n) Rated voltage line winding;
p) Rated voltage cell winding;
q) Rated current on line side;
r) Rated current on cell side; and
s) Temperature rise (Table 3).

NOTE — In the case of outputs below 100 kW, a simplified rating plate is permissible

5.3.2 Assemblies and equipment may also be marked with Standard Mark.

5.3.2.1 The use of the Standard Mark is governed by the provisions of the Bureau of Indian Standards Act, 1986 and the Rules and Regulations made thereunder. The details of conditions under which the licence for the use of Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

---

*Specification for power transformers.

5.4 Tests

5.4.0 Tests given in IS : 2026-1962* shall be applied to rectifier transformers with the modifications given in **5.4.1** to **5.4.4**.

5.4.1 *Commutating Reactance Test* — This test is applicable to the rectifier transformers and shall be carried out as a type test.

For connections 2, 3, 5, 9, 10 and 11 the commutation reactance may be determined from a three-phase short-circuit test according to Table 1.

For connections 1, 4, 6 and 12 and any other connection, not listed in Table 1, the commutating reactance shall be determined as described below.

A single-phase short-circuit test shall be used to obtain the commutating reactance and, if required, the inductive dc voltage drop. In this test all line terminals of the transformer are short-circuited and an alternating current of rated frequency and of magnitude 0·354 I_{dl}/g is fed through two consecutive (commutating) phases on the cell side. In the formula, I_{dl} is the rated direct current and g is the number of commutating groups among which I_{dl} is divided. All windings on the cell side whose commutations coincide with these two phases, shall be connected in parallel during the test.

The reactive component of the input voltage, expressed as a percentage of the rated voltage between the two terminals, gives the commutating reactance from which the reactive voltage drop, due to the transformer, may be calculated.

5.4.2 *Losses and Voltage Drops in Transformers and Reactors*

5.4.2.1 *No-load (no-load losses and no-load current) test* — The no-load losses shall be measured as in IS : 2026-1962* at rated voltage and rated frequency. The core loss of transformers which have a non-sinusoidal wave-shape of the normal operating voltage shall be determined by applying a sinusoidal voltage having the same arithmetic mean value and the same fundamental frequency as that of the applied voltage in service.

5.4.2.2 *Measurement of losses in the windings (load losses)* — The losses in the windings which appear under normal service conditions are composed of the losses in winding resistance as measured by dc and the additional losses (depending on frequency) caused by eddy currents. Due to the harmonics, the actual losses in the windings would require to be measured with the transformer in normal operation with the rectifier assembly. This method of measurement cannot be recommended as it is too complicated and inaccurate. Therefore, the losses in the windings are to be computed from the result of short-circuit measurement carried out with sinusoidal currents. The method is based on the use of sinusoidal currents in the winding having the same rms values as those which would exist in operation with the rectifier assembly if the overlap was disregarded. This holds for double-way transformers. For single-way transformers, *see* Table 1.

---

*Specification for power transformers.

Owing to the fact that the rms values of the currents during normal operation with the rectifier assembly are somewhat smaller than those in the test, a *positive error* is encountered. This positive error is assumed to be compensated for by the *negative error* resulting from the fact that the additional stray losses caused by the harmonics in operation with the rectifier assembly are disregarded.

If not otherwise specified, the guaranteed losses in the windings refer to operation on the principle tap of the winding.

Table 1 indicates, for some of the most commonly used connections, the short-circuit connections to be made for tests A, B and C respectively.

Short-circuit tests — For each short-circuit test A, B and C respectively, rated line side current of rated frequency is to be fed into all line side terminals, with the cell side terminals short-circuited as indicated in Table 1. The power inputs shall be measured in the short-circuit tests A, B, C and are designated P_A , P_B , P_C , respectively. The total losses in the windings are then calculated by the formulae given in Table 1.

5.4.2.3 *Losses in interphase transformers, current balancing reactors, series smoothing reactors, transductors and current regulating reactors*

a) *Interphase transformers* — The manufacturer shall state the calculated iron loss at rated current, rated voltage and specified amount of phase control.

   The losses in the winding are to be calculated as the product of the dc resistance and the square of the direct current in the winding.

b) *Current balancing reactors* — The iron losses in current balancing reactors are by convention to be ignored.

   The losses in the winding are to be calculated as the product of the dc measured resistance and the square of the rms current in the winding, calculated on the basis of rectangular shaped current waveform.

c) *Series smoothing reactor* — The iron losses are, by convention, to be ignored.

   The losses in the winding are to be calculated as the product of the dc resistance and the square of the direct current in the winding.

d) *Transductors and current regulating reactors* — The *iron losses* shall be calculated at rated current and rated voltage.

The *losses in the power winding* shall be calculated as the product of the dc measured resistance and the square of the rms current in the winding, calculated on the basis of ideal current waveform (ignoring stray inductances). When the power winding consists of heavy conductors, the eddy current losses should be estimated by calculation and added.

5.4.3 *Temperature Rise Test for Main and Interphase Transformers to Rating Class G* (*see* **6.2**) — The following values shall be determined from the specified loads or from the specified load cycle (if any), whichever be the more onerous:

I_A = rms value of the current over the most onerous period of 10 hours in the case of oil-immersed transformers or of 5 hours in the case of air-cooled transformers;

I_B = rms value over the most onerous period of $\frac{1}{2}$ hour.

From these values, a factor F is to be determined from Table 2. The equivalent continuous rating of the transformer is then equal to the product $I_A \times F$.

The transformer temperature rise, corresponding to steady application of the equivalent continuous rating, shall be determined in accordance with IS : 2026-1962*.

5.4.4 *Insulation (Separate Source Voltage Withstand) Test* — The following test voltages are to be applied unless the values given are lower than those specified in IS : 2026-1962* in which case the latter values shall be applied.

a) *Main transformers* — As for power transformers.

b) *Interphase transformers and current balancing reactors* — As for power transformers of appropriate type and with the same voltage class as that of the cell winding of the main transformer. However, if the interphase transformer or the current balancing reactors are connected to the dc end of the rectifying elements and are of dry type the same test voltage as for the rectifier stacks shall apply. (*See* IS : 3895-1966†).

c) *Series smoothing reactors* — Same as for the rectifier stacks (*see* IS : 3895-1966†). However, if the reactor is oil-immersed in the same tank as the main transformer, the test voltage of the cell winding of this transformer shall apply.

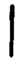
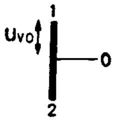
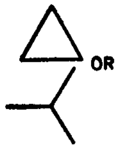
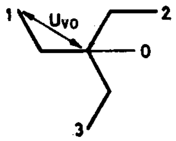
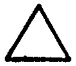
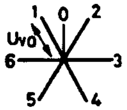
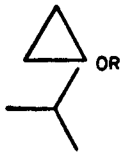
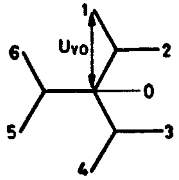
---

*Specification for power transformers.

†Specification for monocrystalline semiconductor rectifier cells and stacks.

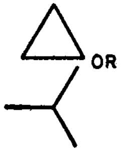
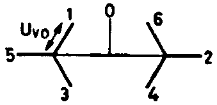
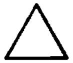
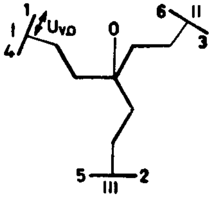
TABLE 1 CONNECTIONS

SINGLE WAY

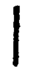
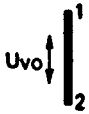
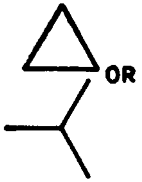
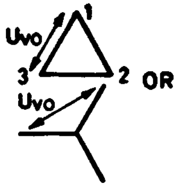
Connection Number	Connections in Vector Representation		$\frac{I_L}{I_d}$ Line Side Current Factor (*see* Note 1)	Tests : Terminals to be Short-Circuited			Total Losses in the Windings	$\frac{U_{dio}}{U_{vo}}$	$\frac{d_{xtl}}{e_{xl}}$
	Line Side	Cell Side		A	B	C			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1			1	0-1	0-2		$\frac{P_A + P_B}{2}$	0·9	0·707
2			0·816	1-2-3			$P_A \frac{1 + 1{\cdot}5k}{1 + k}$	1·17	0·866
3			0·816	1-3-5	2-4-6		$1{\cdot}5\,\frac{P_A + P_B}{2}$	1·35	1·5
4			0·816	1-2 3-4 5-6	2-3 4-5 6-1	Take average of results 1-3-5 and 2-4-6	$\frac{P_A + 2P_B + 3P_C}{6}$	1·35	0·5

(Continued)

TABLE 1 CONNECTIONS — *Contd*

Connection Number	Connections in Vector Representation		$\frac{I_L}{I_d}$ Line Side Current Factor (*see* Note 1)	Tests : Terminals to be Short-Circuited			Total Losses in the Windings	$\frac{U_{dio}}{U_{vo}}$	$\frac{d_{xtl}}{e_{xl}}$
	Line Side	Cell Side		A	B	C			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
5			0·707	1-3-5	2-4-6		$\frac{P_A + P_B}{2}$	1·17	0·5
6			0·544	1-3-5 I-II-III	2-4-6 I-II-III		$1{\cdot}125\ \frac{P_A + P_B}{2}$	0·9	—

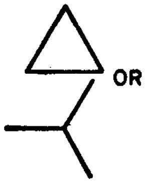
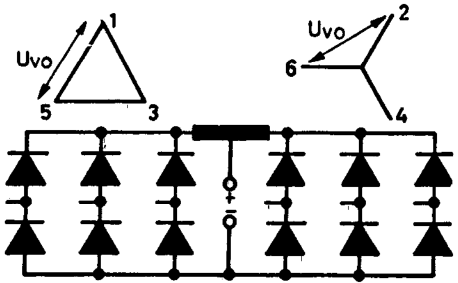
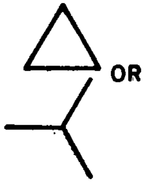
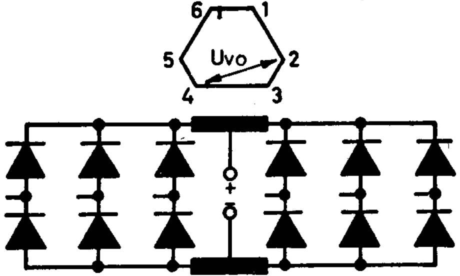
DOUBLE WAY

Connection Number	Line Side	Cell Side	$\frac{I_L}{I_d}$	A	B	C	Total Losses in the Windings	$\frac{U_{dio}}{U_{vo}}$	$\frac{d_{xtl}}{e_{xl}}$
9		 DOUBLE WAY	1	1-2			P_A	0·9	0·707
10		 DOUBLE WAY	0·816	1-2-3			P_A	1·35	0·5

(*Continued*)

TABLE 1 CONNECTIONS — *Contd*

DOUBLE WAY

CONNECTION NUMBER	CONNECTIONS IN VECTOR REPRESENTATION		$\frac{I_L}{I_d}$ LINE SIDE CURRENT FACTOR (*see* NOTE 1)	TESTS: TERMINALS TO BE SHORT-CIRCUITED			TOTAL LOSSES IN THE WINDINGS	$\frac{U_{dio}}{U_{vo}}$	$\frac{d_{xtl}}{e_{xtl}}$
	Line Side	Cell Side		A	B	C			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
11			0·789	1-3-5	2-4-6		$\frac{P_A + P_B}{2} \cdot \frac{1 + 0{\cdot}27k}{1 + 0{\cdot}5k}$	1·35	0·26
12			0·789	Take average of results 1-3-5 and 2-4-6	2-3 4-5 6-1	1-2 3-4 5-6	$1{\cdot}34\, P_A - 0{\cdot}08\, P_B - 0{\cdot}27\, P_C$	1·35	0·26

k = the quotient of the sum of the losses in the cell windings divided by the losses in line winding in the short-circuit test, as determined from the ohmic resistances of the windings.

NOTE 1 — *Line side current factor* — The rms value I_l of the line side current per ampere of direct current I_d, is indicated in the above Table 1, on the basis of the following voltage ratios and on the assumption of smooth direct current:

a) For single-way connections:

$$\frac{\text{Phase-to-phase voltage on line side}}{\text{Phase-to-netural voltage on cell side}} = 1$$

b) For double-way connections:

$$\frac{\text{Phase-to-phase voltage on line side}}{\text{Phase-to-phase voltage on cell side}} = 1$$

NOTE 2 — *Ideal no-load dc voltage* U_{dio} — This voltage may be computed from the rated voltage U_{vo} of the cell winding for the connections given in Table 1 by the factors given in the column $\frac{U_{dio}}{U_{vo}}$.

NOTE 3 — *The inductive dc voltage drop dxt* — For $\frac{d_{xtl}}{e_{xtl}}$ (*see* **6.3.3.4**).

As in the Original Standard, this Page is Intentionally Left Blank

TABLE 2 VALUES OF FACTOR F

I_B/I_A	Factor F For oil-immersed transformers	 For air-cooled transformers
to 1·1	1·01	1·06
1·101 „ 1·2	1·03	1·12
1·201 „ 1·3	1·06	1·18
1·301 „ 1·4	1·09	1·24
1·401 „ 1·5	1·13	1·30
1·501 „ 1·6	1·17	1·36
1·601 „ 1·7	1·21	1·42
1·701 „ 1·8	1·25	1·48
1·801 „ 1·9	1·29	1·54
1·901 „ 2·0	1·34	1·60
2·001 „ 2·1	1·39	1·66
2·101 „ 2·2	1·44	1·72
2·201 „ 2·3	1·49	1·78
2·301 „ 2·4	1·54	1·84
2·401 „ 2·5	1·60	1·90
2·501 „ 2·6	1·66	1·96
2·601 „ 2·7	1·72	2·02
2·701 „ 2·8	1·78	2·08
2·801 „ 2·9	1·84	2·14
2·901 „ 3·0	1·91	2·20

6. RECTIFIER ASSEMBLIES AND EQUIPMENTS

6.1 Electrical Connections and Calculation Factors

6.1.1 *Connections* — Table 1 shows the most commonly used transformer connections. The transformer connections 1 to 6 are used together with rectifier stacks in single-way connections. The transformer connections 9 to 12 are used together with rectifier stacks in double-way connections.

6.1.2 *Calculation Factors*

a) *Voltage ratio* — Table 1 gives the ratio

$$\frac{U_{dio}}{U_{vo}}$$

for the different connections

where

U_{dio} = ideal no-load dc voltage, and

U_{vo} = transformer cell winding voltage as shown in Table 1.

This figure is to be used in the calculations according to this standard.

b) *Voltage regulation* — Table 1 gives the ratio

$$\frac{d_{xtl}}{e_{xl}}$$

for the different connections

where

d_{xtl} = the dc voltage regulation at rated load, due to the transformer reactance, and expressed as a percentage of ideal no-load dc voltage, and

e_{xl} = the inductive component of the transformer impedance voltage at rated load expressed as a percentage of nominal ac voltage.

This figure is to be used in the calculations according to this standard. (*See also* **6.3.4**.)

6.2 Rating Classes

6.2.1 In fixing the overloads (if any) which a rectifier equipment is to be capable of carrying, it shall be borne in mind that the overloads which would fit the particular service may not necessarily fit the natural overload characteristics of the rectifier assembly or the natural overload characteristic of the transformer and associated apparatus, and a compromise is necessary. This standard, therefore, establishes a number of rating classes, which are broadly suitable for the different types of service against each class.

6.2.1.1 Rectifier equipments rated in accordance with this standard shall, according to their class, be capable of carrying the loads according to Table 3 without injury. Table 3 also gives the maximum permissible temperature rise of the transformer windings.

NOTE 1 — In rating classes *C* and *F*, it should be noted that, although in the rated load cycle 100 percent load is permitted for six hours, or three hours respectively, before the application of any of the alternative overloads as indicated in **6.2.1**, the rms value of the load cycle may be maintained at rated direct current for eight hours.

NOTE 2 — For the classes *C* and *F*, the test condition for the limit of transformer winding temperature rise is, after six hours at rated direct current, starting at room temperature.

TABLE 3 RATING CLASSES

RATING CLASS	SERVICE CONDITIONS, TYPE OF COOLING AND INSULATION CLASS TO BE SPECIFIED BY PURCHASER TO SUIT HIS REQUIREMENTS				TEST CONDITIONS FOR LIMIT OF TRANSFORMER WINDING TEMPERATURE RISE MEMSURED BY RESISTANCE METHOD	
	Most Suitable Applications	Rated Load Cycle of the Rectifier Equipment in Percent of Rated Direct Current	Type of Cooling	Insulation Class	Maximum Allowable Temperature Rise, °C	Load
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	Electrochemical processes	100% continuous	Air	*A*	55	After continuous load
				B	75	
			Liquid	*A*	55	
B	Electrochemical processes	100% continuous	Air	*A*	55	After continuous load
		150% 1 min		*B*	75	
			Liquid	*A*	55	
C	Industrial service	100% 6 h	Air	*A*	40	After 6 h
		125% 2 h		*B*	55	After continuous load 100%
		200% 10 s	Liquid	*A*	55	
D	Industrial service	100% continuous				After continuous load
		125% 2 h	Liquid	*A*	55	
		200% 10 s				
E	Medium traction and mining	100% continuous	Air	*A*	35	After continuous load
		150% 2 h		*B*	50	
		200% 1 min	Liquid	*A*	50	
F	Heavy traction	100% 3 h	Air	*A*	30	After 6 h at 100%
		150% 2 h		*B*	45	
		300% 1 min	Liquid	*A*	50	
G	Agreed duty cycle	To be agreed between purchaser and manufacturer	Air	*A*	55	After continuous load
				B	75	
			Liquid	*A*	55	

6.2.1.2 Notwithstanding the rating class assigned to the rectifier equipment, its constituent rectifier stacks and assemblies shall be capable of withstanding accidental overloads within the limits permitted by the protective devices as supplied or recommended by the manufacturer.

6.2.1.3 When the temperature rise of all the parts of the rectifier unit is at or below that corresponding to rated value, the unit shall be capable of withstanding a momentary over-current of such magnitude and duration as is necessary to allow the associated automatic load regulating equipment or over-current protection equipment to protect all the parts from injury.

6.2.2 *Most Suitable Applications*

6.2.2.1 Classes *A* and *B* are intended for operation at rated direct current for long periods of service, extending to years, as is the case for electrochemical service.

Classes *C* and *F* are intended to meet the needs of those applications in which the rms value of load cycle may be maintained at rated direct current of the rectifier for 8 hours followed by not more than 70 percent of rated direct current for 16 hours during a 24 hour period.

Classes *D* and *E* are intended to meet the needs of those applications where the rms value of the load cycle measured over any 24 hour period may be maintained at rated direct current of the rectifier for indefinitely long periods.

6.2.3 *Load Cycles*

6.2.3.1 For rating classes *C* and *F*, currents in excess of rated direct current may only be applied separately, each following the reaching of temperature conditions which would prevail if the rectifier equipment was started at room temperature and then operated at rated direct current for the period specified for 100 percent of rated direct current.

For rating classes, *B*, *D* and *E*, currents in excess of rated direct current may only be applied separately, each following the reaching of temperature conditions not exceeding the constant temperature conditions of continuous operation at 100 percent of rated direct current.

6.3 Declaration of Losses or Efficiency, Power-Factor and Regulation

6.3.1 *Losses and Efficiency*

6.3.1.1 The efficiency of the rectifier equipment is the ratio of the output to the sum of output and the included losses.

For units not exceeding 100 kW rated output and rated currents not exceeding 5 000 A and for single-phase equipment of all sizes, the efficiency may be declared in terms of input-output method of measurement or by the method of summation of measured losses, at the choice of the manufacturer. For all other units, the summation method shall apply as follows.

The overall efficiency includes the losses in all parts of the rectifier equipment which are normally in operation (transformer, reactors and cells) and the power absorbed by additional apparatus which is included. If certain of the apparatus incorporated with the equipment is not taken into account for the total efficiency, the power absorbed by this shall be stated separately.

For certain components in the rectifier equipment the following shall be considered.

6.3.1.2 The following losses shall be included when determining the efficiency:

a) The internal losses in the rectifier assembly, such as losses in the cells and their connections including losses in fuses, potential dividers, current balancing means, capacitor-resistor damping circuits and voltage surge diverters.

b) Losses in transformer, interphase transformer, current limiting and balancing reactors between transformer and rectifier assemblies and the losses of transductors and other current regulating reactors, induction regulators, regulating transformers, and the losses of main transformers and reactors forming part of the rectifier equipment.

c) Power absorbed by auxiliaries, such as permanently connected fans or pumps, amplifiers.

d) Losses in series smoothing reactors and in wave filters when built into the equipment.

e) Power absorbed by apparatus for reducing the no-load voltage rise, if continuously in circuit.

6.3.1.3 The following losses shall not be included when determining the efficiency but shall be stated separately if requested, when the apparatus concerned is supplied by the manufacturer of the rectifier equipment:

a) Losses due to the main connections between transformer and rectifier assembly, and in the main connections to circuit-breakers, isolators, switches and to the load.

b) Losses in circuit-breakers, isolators, switches and in control gear other than the items mentioned in **6.3.1.2** (a) to (e).

c) Losses due to heating and ventilation of the building and in the cooling supply.

d) Losses due to the loading resistance, if any, for absorbing regenerated current from the dc network.

e) Losses due to auxiliary apparatus which operates only intermittently.

f) Losses in the series smoothing reactor or wave filter or both, when mounted separately.

6.3.1.4 In any case of doubt whether the losses of a component of the rectifier epuipment should be included or not when calculating the efficiency, it is to be stated whether the losses in it are included in the declared efficiency.

6.3.2 *Power-Factor*

6.3.2.1 For rectifiers with a pulse number of 6 or more, the total power-factor λ is of little practical interest; the value which is useful for normal purposes is the displacement factor cos ϕ.

For this reason, if a guarantee is required, it shall, unless otherwise specified, refer to the displacement factor and to voltages of the ac network which are both symmetrical and sinusoidal.

Declaration of the displacement factor is required only if so agreed between the supplier and the purchaser. When required, the displacement factor shall be determined by calculation from the measured reactances and magnetizing current of the components of the equipment *except that* for equipment not exceeding 100 kW rated output and rated currents not exceeding 5 000 A the manufacturer may measure the displacement factor directly.

For single-phase equipment exceeding 100 kW rated output, the method of determining the displacement factor is to be agreed between the purchaser and the supplier.

6.3.2.2 Saturable reactors, transductors, affect the power-factor, voltage drop and ripple voltage of a rectifier in three ways:

a) *Air-core reactance (at full saturation)* — This merely adds to normal commutating impedance.

b) *Magnetization current below saturation knee* — This produces the effect of phase delay.

c) *Slope of magnetization curve from residual to maximum flux density* — This produces both the effect of (a) and (b) in varying degrees.

6.3.3 *Inherent and Total Voltage Regulation*

6.3.3.1 The inherent voltage regulation is given by the sum of the dc voltage drops produced by the transformer and other parts of the rectifier, for example, reactors, etc, plus the change in forward voltage drop with load in the rectifier assembly.

The voltage drops shall refer to the principal tap of the transformer.

When it is necessary to determine the value of the inherent voltage regulation, this shall be calculated according to this clause from the resistances and reactances of the components of the equipment measured according to this standard *except that*, for equipment not exceeding 100 kW rated output and rated current not exceeding 5 000 A, the voltage regulation may, if so preferred by the manufacturer, be determined by direct measurement in an input-output load test on the equipment.

For single-phase equipment exceeding 100 kW rated output, the method of determining the inherent voltage regulation is to be agreed between the purchaser and the supplier.

6.3.3.2 *Determination of the resistive voltage drop d_{rtl} due to the main and interphase transformer expressed as a percentage of the ideal no-load dc voltage* — This is calculated by the formula:

$$d_{rtl} = \frac{\text{Watt losses in transformer windings at rated direct current}}{\text{Rated direct current} \times \text{Ideal no-load dc voltage}} \times 100$$

6.3.3.3 *Determination of the resistive voltage drop d_{rbl} due to other components (for example, series smoothing reactors, regulating transformers, line side reactors, etc) expressed as a percentage of the ideal no-load dc voltage* — This is calculated by:

$$d_{rbl} = \frac{\text{Watt losses in power windings at rated direct current}}{\text{Rated direct current} \times \text{Ideal no-load dc voltage}} \times 100$$

6.3.3.4 *Determination of the inductive dc voltage drop d_{xtl} due to the transformer* — d_{xtl} at rated direct current, expressed in percent of the ideal no-load dc voltage may, for connections 2, 3, 5, 9, 10 and 11 of Table 1, be computed as the product of the factor given in the last column of the table and the quantity e_{xl}. This quantity e_{xl} is the reactive component of the short-circuit voltage measured at the line side current I_{Ll} by short-circuit test *A* in the case of connections, 2, 9, 10 and 11, and as the mean value given by tests *A* and *B* in the case of connections 3 and 5 and as expressed in percent of the rated voltage of the line winding. For the connections enumerated above, this shall be the normal method of computing d_{xtl}.

For all other connections, and those connections mentioned in Table 1, but not included earlier in the above paragraph, the method described in **5.4.1** is recommended. In that method d_{xtl} is measured directly.

6.3.3.5 *Determination of the inductive dc voltage drop d_{xbl} due to other reactances (for example, regulating transformers, line side reactors, current balancing reactors, etc)* — The values of d_{xbl} are calculated according to the following formulae:

a) For reactors, transformers, etc, one line-side or with double-way connections, for reactors on cell winding side:

   1) For 3-phase ac systems:

$$d_{xbl} = 100. \sqrt{3} \sin \frac{\pi}{p} \cdot \frac{I_{bl}\ X_b}{U_{bl}}$$

   2) For single-phase ac system:

$$d_{xbl} = 100. \frac{1}{\sqrt{2}} \cdot \frac{I_{bl}\ X_b}{U_{bl}}$$

b) For cell side reactors (arm reactors) with single-way connections:

$$d_{xbl} = 100. \frac{q^2}{2\pi p} \cdot \frac{I_{dl}\ X_b}{U_{dio}}$$

The symbols used in these formulae have the following meanings:

X_b = reactance per phase of reactor, transformer, etc, in ohms

I_{bl} = rms current in reactor corresponding to rated direct current I_{dl}, calculated on the basis of rectangular current wave form

U_{bl} = rated phase-to-phase voltage at the reactor, etc

U_{dio} = ideal no-load dc voltage

I_{dl} = rated direct current of convertor

p = pulse number

q = commutating number

6.3.3.6 *Determination of the total dc voltage drop produced by transformers, reactors, etc* — The total dc voltage drop at rated current, expressed as a percentage of the ideal no-load voltage is given by:

$$(d_{rtl} + d_{xtl}) + (d_{rbl} + d_{xbl}) = d_{tl} + d_{bl}$$

where

d_{tl} = total dc voltage drop at rated direct current due to main and interphase transformer (if any) as a percentage of U_{dio}; and

d_{bl} = total dc voltage drop at rated direct current, due to other parts of the convertor, for example, reactors, etc, as a percentage of U_{dio}.

6.3.4 *Influence of ac System Impedance on dc Voltage Regulation of the Convertor* — The load of the convertor may change the rms value and the wave form of the ac voltage at its line-side terminals. This influence depends upon the pulse number and the ratio of the load on the convertor to the short-circuit capacity of the ac system, based upon the impedance of the network as seen from the line-side terminals of the convertor. Resonance phenomena, which may be caused by the presence of large capacitor banks, may result in uncontrollable changes in dc voltage.

Also when, as assumed in this specificatian, the rms value of the line voltage on the ac terminals of the convertor is kept constant, the influence of ac reactance on waveform causes an additional voltage drop to appear on the dc terminals of the convertor.

6.3.5 *Information to be Given for the Calculation of the Additional dc Voltage Regulation Due to ac System Impedance* — To enable the manufacturer to calculate the effect of ac system impedance, the purchaser should give the ac system data before the order. When the system short-circuit capacity is given for this purpose, the value given shall correspond to that configuration of the ac system for which the total voltage regulation is to be calculated.

6.3.5.1 *dc voltage regulation when the resistance and reactance of the ac system are known* — The manufacturer shall indicate the following two values:

a) The inherent voltage regulation of the convertor; and

b) The total voltage regulation of the convertor, when the rms value of the line-side terminal voltage is kept constant.

6.3.5.2 *dc voltage regulation when the resistance and reactance of the ac system are not given by the purchaser* — The manufacturer shall indicate the following two values:

a) The inherent voltage regulation of the convertor; and

b) The total voltage regulation of the convertor for constant rms voltage on its ac terminals, assuming some finite value of the short-circuit capacity of the ac system.

The manufacturer may, alternatively, draw the purchaser's attention to Fig. 3 by which the total voltage regulation can be computed for any value of the short-circuit capacity of the ac system.

6.3.6 *Calculation of the Additional dc Voltage Regulation D_{LI} due to ac System Impedance* — Fig. 3 gives the additional dc voltage drop d_{LI} at rated direct current, due to ac system impedance. The corresponding dc regulation D_{LI} is :

$$D_{LI} = \frac{d_{LI} \cdot U_{dio}}{100} \text{ in volts}$$

6.3.6.1 D_{LI} is to be added to the inherent voltage regulation to give the total voltage regulation of the convertor.

6.3.6.2 If not otherwise stated, it is assumed that the rms value of the line side terminal voltage of the convertor is kept constant.

6.3.6.3 *Legend to Fig. 3 curves for determination of additional dc voltage drop due to ac system impedance*

a) Ordinate:

d_{LI} = required additional dc voltage drop due to ac system impedance expressed in percent of the ideal no-load dc voltage, at rated direct current I_{dl}, when the rms voltage on line-side terminal is kept constant.

b) Abscissa: $\frac{U_{dio} \cdot I_{dl}}{Q}$

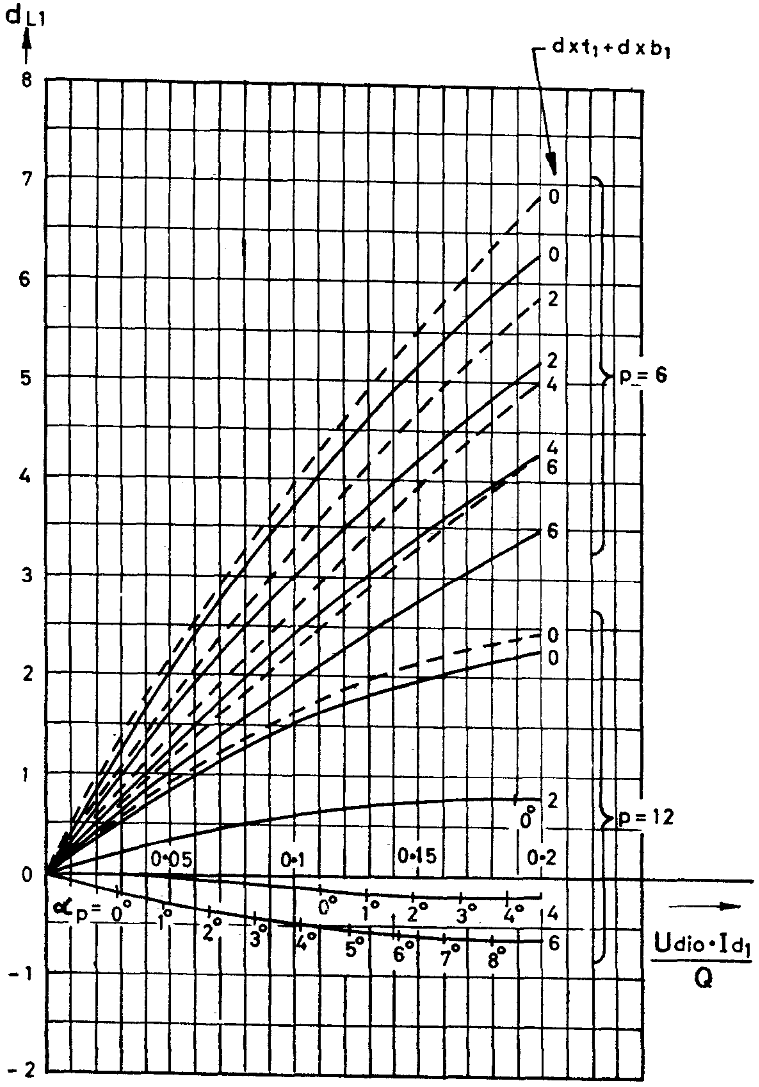


FIG. 3 CURVES FOR DETERMINATION OF ADDITIONAL dc VOLTAGE DROP DUE TO ac SYSTEM IMPEDANCE AT RATED DIRECT CURRENT

where

Q = short-circuit capacity of the ac system in VA, based on its impedance;

U_{dio} = ideal no-load dc voltage, in volts; and

I_{dl} = rated direct current of the convertor.

c) Parameters: $d_{xtl} + d_{xbl}$

where

d_{xtl} = inductive dc voltage drop at rated direct current I_{dl} due to the transformer, in percent of the ideal no-load dc voltage;

d_{xbl} = inductive dc voltage drop at rated direct current I_{dl} due to other parts of the convertor, e.g. reactors etc, if any, in percent of the ideal no-load dc voltage;

p = pulse number; and

α_p = inherent delay angle.

d) Ratio of resistance to reactance of ac system $\begin{cases} = 0 \\ = 0{\cdot}2 \end{cases}$ ....

e) The inherent delay angle α_p in this figure is zero except where values of α are indicated. This delay occurs in 12-pulse connections in certain p operating conditions, even where no phase control is applied.

6.3.6.4 When using the curves of Fig. 3 for other loads than rated load, the actual values of I_d, d_{xt} and d_{xb} have to be taken to obtain the actual drop d_L and from this the actual additional regulation D_L. That is:

$$(d_{xt} + d_{xb}) = (d_{xtl} + d_{xbl})\frac{I_d}{I_{dl}}$$

6.3.7 *Measurement of the Additional dc Voltage Regulation Due to ac System Impedance*

6.3.7.1 A voltmeter on the dc side of the convertor does not indicate the inherent voltage regulation but a larger regulation.

6.3.7.2 The influence of the ac system impedance cannot be measured directly by a voltmeter indicating the rms value on the ac side.

6.3.7.3 The influence of the ac system impedance may be appreciated by examination of an oscillographic record of the ac voltage taken when the convertor is on load.

6.3.7.4 While the convertor is operating, the additional dc voltage regulation due to the ac system impedance can be measured with sufficient approximation by a special measuring circuit using a small rectifier connected to the line-side terminals of the convertor, through a transformer, if necessary.

This small rectifier shall have the same commutating and pulse number as the convertor, and the ripples of its dc voltage shall have the same relative phase position to the ac network voltage as the ripples of the convertor dc voltage.

The percent change in the output dc voltage of the small rectifier during a change of the convertor load represents the percent change in the dc voltage of the convertor due to the ac system impedance.

6.3.8 *Corrected Voltage Regulation* — If an automatic voltage regulator is used, the effect of this regulator shall be declared for specified variations of those quantities, the influence of which is to be counteracted.

6.3.9 *ac Components on the dc Side* — This clause does not refer to rectifier equipment for railway substations. For others, refer **7.5** of IS : 3136-1965*.

6.4 Performance Requirements

6.4.1 *Rectifier Cells and Stacks* — Rectifier cells and stacks used in rectifier equipment shall comply with IS : 3895-1966†.

6.4.2 *Transformers, Transductors and Reactors* — Transformers, transductors and reactors used in rectifier equipment shall comply with **5.**

6.4.3 *Auxiliary Apparatus, Other than According to* **6.4.1** *and* **6.4.2** — Auxiliary appartus fitted in equipment, such as motors, control gear, etc, shall comply with the appropriate Indian Standard for the apparatus.

6.4.4 *Parallel Operation of Unregulated Rectifier Assemblies and Equipment*

6.4.4.1 This clause relates to rectifier assemblies for use, where the transformer is supplied separately.

For identical rectifier assemblies forming part of the same equipment and operating under similar conditions in parallel, precautions shall be taken to ensure that each rectifier assembly operates within its ratings.

6.4.4.2 The following clauses relate to individual rectifier equipment which are required to operate in parallel on the dc side with other sources of direct current:

a) If the rectifier equipment is required to operate in parallel on the dc side with other sources of direct current having dissimilar characteristics, the requirements for load sharing shall be agreed between the purchaser and the supplier.

b) In the case of identical equipments constructed at the same time by the same manufacturer, operating under similar conditions and in parallel in the same location, fed by the same ac supply, the direct current of each equipment shall not differ by more than 10 percent from its correct share at 90 percent of rated load (or at such other load as may be agreed between the purchaser and the supplier). At the rated overloads the equipment shall be capable of carrying the aggregate rated overload without injury to the equipment.

---

*Specification for polycrystalline semiconductor rectifier equipment.

†Specification for monocrystalline semiconductor rectifier cells and stacks.

NOTE — When in service the continuous, 6-hour, 3-hour or 2-hour rated currents should not be exceeded.

6.4.4.3 This clause relates to the load sharing requirements for a number of rectifier equipment forming a comprehensive installation of specified aggregate capacity.

When a group of rectifier equipment, ordered at the same time, is required to operate in parallel to supply a load of total specified magnitude, the manufacturer shall declare the maximum deviation from correct load sharing between individual equipment as a percentage of the nominal equipment rating and shall increase the nominal rating of each equipment by this same amount and state it on the rating plate of each equipment, to ensure that the total specified load may be supplied without injury to the most heavily loaded equipment.

NOTE — The loads imposed on any one of the individual equipment should not exceed the rating assigned to it by the manufacturer.

6.4.5 *Parallel Operation of Regulated Rectifier Equipment* — For regulated rectifier equipment (that is, those which are provided with means for voltage adjustment) which are required to operate in parallel on the dc side, the requirements for load sharing shall be agreed between the purchaser and the supplier.

6.5 Protection

6.5.1 *Fault Current Protection* — A monocrystalline rectifier equipment shall be provided with such protective devices as are normal for electrical equipment. In addition, the low thermal capacity and high current density of the monocrystalline cells make it necessary to introduce special protective devices and to co-ordinate the short-time load capacity of the cells with the characteristics of the protective devices and the circuit. The protective equipment to be used depends on the disturbances to be expected, the kind of service of the equipment, economic considerations, etc. For the sake of determining the purpose, properties and principles of such equipment, the definitions given in this standard should be used.

6.5.1.1 With regard to over-current protection for monocrystalline equipment, the following kinds of faults are recognised:

a) *Cell short circuit* — Internal short circuit of a cell due to any cause, for example, over-voltage in the reverse direction, over-heating or internal weakness.

NOTE — A cell failure always begins as a short circuit, but in some cases it ends as an interruption. In this connection, only the short circuit interval is of interest.

b) *Complete dc short circuit* — A short circuit on the dc side having so low an impedance that the current is determined mainly by the internal impedance of the equipment and the impedance of the ac supply system.

NOTE — A complete short circuit may be caused, for example, by a foreign object or by an arc-back in a mercury-arc rectifier equipment operating in parallel with the semiconductor rectifier equipment.

c) *Inductive dc short circuit* — A short circuit on the dc side through an inductance large enough to limit the rate-of-rise of the short-circuit current significantly.

NOTE — Such a short circuit may occur if the short-circuit point is so distant from the rectifier equipment that the inductance of the conductors is appreciable.

d) *Limited dc short circuit* — A short circuit on the dc side where the current or duration or both is limited.

NOTE — A limited short circuit may occur, for example, when a tool is accidentally dropped between the busbars of a big rectifier equipment. The short-circuiting object will then be blown away so quickly that no complete short circuit will have time to develop.

e) *Branch short circuit* — A short circuit in a branch of a dc distribution system, fed by the semiconductor rectifier equipment, where the branches have separate protective devices, each having ratings much lower than the rated current of the rectifier equipment.

NOTE — A branch short circuit may sometimes give rise to a considerable short-circuit current, which is, however, cleared quickly because of the low ratings of the protective device of the branch.

6.5.1.2 Service requirements may be classified under two general headings according to the effects resulting from cell failures:

a) when no interruption or reduction of load is permissible, and

b) where temporary reduction of load is tolerable.

In the first case, provision may be required for cell replacement under load.

6.5.1.3 Either the same or independent means may be used to protect the equipment against the consequences of a cell failure and against the consequences of a dc short circuit.

The means to be used depend on the requirements of the service the kind of short circuit, which might occur, the method to be used for putting the equipment into service again, economical evaluation of the safety, the cost of protective gear, etc. The purchaser and the supplier shall agree on the protection to be adopted.

6.5.2 *Over-voltage Protection*

6.5.2.1 Monocrystalline cells may fail if the reverse voltage applied to them, even of a very short duration, exceeds their reverse voltage capability. Attention, is, therefore, drawn to the need for co-ordination of the surge voltage protection and reverse voltage capability of the cells used.

6.6 Tolerances on Guarantees

6.6.1 If guarantees are given, they shall refer to rated conditions.

6.6.2 When guarantees are made subject to tolerances, the tolerances stated below shall apply. When the values are given without tolerances, they are maximum or minimum values, as the case may be.

a) Assembly losses	+ 10 percent of guaranteed value
b) Losses of transformer and reactor, if any	+ 10 percent of the total guaranteed value
c) Efficiency of the rectifier equipment	Efficiency tolerances corresponding to + 10 percent of the total losses with a minimum efficiency tolerance of — 0·5 percent
d) Calculated displacement factor: $\cos \phi$	$-0{\cdot}2\,(1-\cos\phi)$
e) Inductive dc voltage drop d_{xtl} of the transformer	± 10 percent of guaranteed value
f) Inherent voltage regulation	± 15 percent of guaranteed regulation
g) Measured dc voltage*	± (1 V + 2 percent of rated dc voltage)

NOTE — Items (e), (f) and (g) do not apply to single-phase equipment.

6.7 Marking

6.7.1 Assemblies and equipment shall be provided with a rating plate marked with the details listed below:

a) Manufacturer's name or trade-mark;
b) Rated direct voltage†;
c) Rated direct current†;

---

*For equipment provided with automatic voltage control, the tolerances on dc voltage shall be agreed between purchaser and manufacturer at the time of making the contract.

†For rating class *G*, the rated output given shall be accompanied by a statement of the duty cycle to which it refers, or from where this information may be obtained.

d) Type of load;
e) Rating class*;
f) Rated input voltage and number of phases;
g) Rated input current per phase;
h) Rated frequency;
j) Type of connection;
k) Overall weight including liquid filling, if any, for items above 100 kg only;
m) Quantity or weight of liquid filling, if any;
n) Cooling requirements;
p) Special operating condition, if any†;
q) Rated current in middle wire, if any; and
r) Country of manufacture.

6.7.2 When a rectifier assembly is intended for incorporation in other equipment, the plate may be provided loose for attachment in a convenient position on that equipment.

6.7.3 When the equipment comprises two or more units which are interconnected, the rating plate shall be fitted on one of the units and additional plates fitted to other items, marked with the manufacturer's name and the identification reference for the item.

6.8 Tests

6.8.1 *General*

6.8.1.1 *Type tests* — The following shall constitute the type tests:

a) Power losses in rectifier assemblies (**6.8.2**);
b) Power consumption of auxiliaries (**6.8.3**);
c) Equipment reactance (**6.8.4**);
d) Test for transformers, phase shifters, regulating equipment, transductors, reactors and saturable reactors (**6.8.5**);
e) Connection checking (**6.8.6**);

---

*For rating class *G*, the rated output given shall be accompanied by a statement of the duty cycle to which it refers, or from where this information can be obtained.

†When the rectifier equipment is designed to operate under special conditions, such as altitudes above 1 000 m or under ambient temperature conditions, differing from those specified in **4.1**, these special conditions shall be stated on the rating plate.

f) Measurement of voltage regulation (**6.8.7**)*;
g) Automatic voltage regulator operation (**6.8.8**)*;
h) Efficiency measurement (**6.8.9**)*;
j) Measurement of power factor (**6.8.10**)*;
k) Temperature rise (**6.8.11**)*;
m) Insulation test (**6.8.12**)*;
n) Inspection (**6.8.13**)*;
p) Auxiliary devices (**6.8.14**)*; and
q) Alternating current measurement (**6.8.15**)*.

6.8.1.2 *Routine tests* — The following tests shall be carried out as routine tests:

a) Connection checking (**6.8.6**),
b) Measurement of voltage regulation (**6.8.7**)*,
c) Insulation test (**6.8.12**)*,
d) Inspection (**6.8.13**)*,
e) Auxiliary devices (**6.8.14**)*, and
f) Alternating current measurement (**6.8.15**)*.

6.8.1.3 Tests on rectifier assemblies and equipment shall normally be carried out at rated service conditions. Where this is impossible or practically unsuitable, the tests may be carried out under other conditions which shall be stated.

6.8.2 *Power Losses in Rectifier Assemblies*

6.8.2.1 When power loss measurements are required, they should be carried out as short-circuit measurements on the rectifier assembly at rated frequency. Then the losses due to reverse current and voltage are assumed to be negligible. When the power losses in voltage divider resistors are not to be ignored, they should be evaluated by calculation.

The following two measurements are made:

a) The losses P_1 are measured at rated current I_{dl},
b) The losses P_2 are measured at the current $k.\ I_{dl}$.

where

$$k = \frac{\text{Form factor of forward current in actual service}}{\text{Form factor of forward current in the test}}$$

---

*These tests are applicable only to rectifier equipment of 100 kW or less and currents not exceeding 5 000 A delivered as mechanically assembled unit.

As the current in the test is practically sinusoidal, the following values of k apply to normally used connections:

Single-phase: $k = 1{\cdot}0$ (practically sinusoidal* waveshape);

Three-phase: $k = 1{\cdot}1$ (practially rectangular waveshape with 120° duration).

For connections giving other waveshapes, k may be calculated from the form factors.

The value of the losses P in actual service is calculated by means of the following formula:

$$P = \left(\frac{k+1}{k} \, . \, P_2\right) - \left(k \, . \, P_1\right)$$

When the rated current of the rectifier assembly is very high, it may be difficult to obtain suitable current transformers. At single-way connections, current transformers cannot be used due to the dc component in the current. In those cases a suitable transformer having as low losses as possible should be used and the power losses are measured on its line side. The values P_1 and P_2 are then obtained from:

$$P_1 = P_{m1} - P_{t1}$$

$$P_2 = P_{m2} - P_{t2}$$

where

P_{m1} and P_{m2} are the measured powers at the transformer line side at direct currents I_d and $k. \, I_d$.

P_{t1} and P_{t2} are the transformer losses in these two cases.

The transformer losses are, for this purpose, measured when the transformer is short-circuited on its cell side according to Table 1.

P_{t1} is measured at a line side current $= \frac{I_L}{k}$

P_{t2} is measured at a line side current $= I_L$

where

I_L is the line side current of the transformer with the rectifier assembly in normal operation.

In double-way connections all cell terminals are short-circuited. In single-way connections with two cell windings per phase, one of the windings on each phase is short-circuited†.

---

*In practical single-phase high-power applications, such as traction service the waveshape will be practically sinusoidal. At highly inductive loads which, however, seldom occur in practice, k is 0·9.

†On three-phase star connection all cell side terminals are short-circuited.

It is assumed here that the iron losses can be ignored at the short-circuit test. When that is not the case, suitable corrections have to be applied.

The losses in conductors between the transformer and the rectifier assembly should be included in P_{t1} and P_{t2}. Therefore, the short-curcuits at the transformer tests should be applied when those conductors are connected to the rectifier assembly.

The losses in the conductor used to short-circuit the rectifier assembly should be evaluated by measuring the voltage drop and be subtracted from the measured losses.

6.8.3 *Power Consumption of Auxiliaries* — The power consumption shall be measured, including that of any control apparatus. When they have already passed the tests and certificates are available, only the insulation test need be repeated. For auxiliaries connected to the cell side, the voltages according to IS : 3895-1966*, shall be applied. Auxiliaries connected to the line side shall be tested in accordance with the appropriate Indian Standard.

6.8.4 *Equipment Reactance*

6.8.4.1 Equipment reactance is the sum of the commutating reactance of the transformers and reactors, if any, determined in accordance with **5.4.1**, plus the commutating reactance of the rectifier assembly. In certain cases, by agreement between the manufacturer and the purchaser, the commutating reactance of the connections between transformer and rectifier assembly shall also be included.

6.8.5 *Transformers, Phase Shifters, Regulating Equipment, Transductors, Saturable and Non-Saturable Reactors*

6.8.5.1 These shall be tested in accordance with **5**. When they have already passed the tests, the tests need not be repeated. If for any reason, it is desirable to repeat the insulation test, the test voltage may be reduced to 75 percent of the voltage used in the component test.

6.8.6 *Connection Checking*

6.8.6.1 Tests shall be made to verify that the rectifier assembly is correctly connected.

They shall comprise:

a) An open-circuit test, and at the manufacturer's choice either:

b) A short-circuit test, or

c) A full power test,

---

*Specification for monocrystalline semiconductor rectifier cells and stacks.

i) For the open circuit test (a), the rectifier assembly shall be supplied with ac at a voltage equal to 110 percent of the rated input voltage and the input current and dc voltage shall be measured.

ii) For the short-circuit test (b), the output terminals shall be short-circuited and an ac voltage of sufficient value to cause rated current to flow shall be connected to the input terminals of the rectifier assembly.

iii) For the full-power test (c), the rectifier assembly shall be supplied at rated ac voltage and loaded at rated current.

6.8.7 *Measurement of Voltage Regulation*

6.8.7.1 The dc voltage-current characteristics shall be plotted for rated character of the load or a circuit which is shown to give the same characteristics.

When conducted as a routine test, such points on dc voltage current characteristic shall be checked which show that the declared values on voltage regulation are fulfilled.

6.8.8 *Automatic Voltage Regulator Operation* — The operation of the automatic voltage regulator or other compensating means shall be checked by varying each one of the quantities (except as regards frequency), the influence of which shall be eliminated while the others are kept constant. Frequency variations test, if required, may be mutually agreed upon between the purchaser and the supplier.

This is preferably done by plotting one dc voltage-current characteristic for each of the maximum, normal and minimum value of the variable quantities.

6.8.9 *Efficiency Measurement* — Tests shall be carried out to prove conformity with **6.3.1**.

6.8.10 *Measurement of Power-Factor* — Tests shall be carried out to prove conformity with **6.3.2**.

For three-phase rectifier equipment up to 20 kW with no current in the neutral, the conventional two-wattmeter method is used, where cos ϕ is calculated from the ratio of the wattmeter readings.

For three-phase rectifier equipment with current in the neutral, the total power-factor is measured by the conventional three-wattmeter method.

For single-phase rectifier equipment, total power-factor is measured as the ratio of input active power to input apparent power.

6.8.11 *Temperature Rise* — Tests shall be carried out according to **5.8** of IS : 3895-1966*, and **5.2** of this standard. The requirements of **6.2** shall be fulfilled for the transformer temperatures. The cell temperature shall not exceed rated values.

6.8.12 *Insulation Test* — It shall be carried out according to **5.5** of IS : 3895-1966*, and **5.4.4** of this standard.

6.8.13 *Inspection* — The equipment shall be subjected to a general inspection for the quality of workmanship and finish.

6.8.14 *Auxiliary Devices* — The functions of auxiliary devices, such as contactors, relays and pumps, shall be checked.

6.8.15 *Alternating Current Measurement* — The alternating line side current in all phases at rated load and at no-load shall be measured and checked.

APPENDIX A

(*Clause* 4.1)

SERVICE AND INSTALLATION CONDITIONS

A-1. NORMAL

A-1.1 Ambient air temperatures:

a) Maximum ambient air temperature	45°C
b) Maximum daily average ambient air temperature	35°C
c) Maximum yearly average ambient air temperature	30°C

A-1.2 Altitude — Not exceeding 1 000 m above mean sea level.

A-2. UNUSUAL

A-2.1 Unusual mechanical stresses, for example, shocks and vibrations.

A-2.2 Cooling water which may cause corrosion or obstruction, for example, sea water or hard water.

A-2.3 Foreign particles in the ambient air, for example, abnormal dirt or dust.

A-2.4 Salt air (for example, proximity to the sea), high humidity, dripping water or noxious gases, for example, mercury vapour (particularly dangerous), chlorine, sulphurous vapours, etc.

A-2.5 Exposure to steam or oil vapour.

A-2.6 Exposure to explosive mixture of dust or gases.

A-2.7 Fluid containing radio active particles.

---

*Specification for monocrystalline semiconductor rectifier cells and stacks.

A-2.8 Ambient temperature, if different from those specified in this standard.

A-2.9 High values of relative humidity and temperature.

A-2.10 Considerable and rapid fluctuations of temperature and humidity.

A-2.11 Altitude of more than 1 000 m above mean sea level.

A-2.12 Superimposed high-frequency voltages.

A-2.13 Frequencies different from 50 c/s.

A-2.14 Unusual conditions not covered by **A-2.1** to **A-2.13** shall also be subject to special agreement betveen the purchaser and the manufacturer.

APPENDIX B

(*Clause* 5.2)

CORRECTIONS TO BE APPLIED WHEN COOLING MEDIUM TEMPERATURE IS HIGHER THAN STANDARD VALUES

B-1. This appendix applies when the specified temperature of the cooling medium exceeds the standard values given in **5.2** by not more than 15°C.

The temperature-rise limits shall be reduced by the amounts given in Table 4.

TABLE 4 REDUCTION OF LIMITS OF TEMPERATURE-RISE FOR COOLING MEDIUM TEMPERATURE HIGHER THAN STANDARD

TRANSFORMERS AND SERIES REACTORS	RATING CLASSES OF CLAUSE 6.2				
	A *B*	*C* *D*	*E*	*F*	*G*
(1)	(2)	(3)	(4)	(5)	(6)
Natural air cooled and cooling by forced ventilation:					
Deduction from limit given in **6.2** per deg C excess in peak cooling air temperature (insulation class *A* or *B*)	1·0	0·7	0·6	0·5	1·0
Fluid-to-air cooling:					
Deduction from limit given in **6.2** per deg C excess in peak annual average, or daily average cooling air temperature, whichever excess is greater (insulation class *A*)	1·0	0·8	0·8	0·8	1·0
Fluid-to-water cooling:					
Deduction from limit given in **6.2** per deg C excess in peak annual average, or daily average cooling water temperature, whichever excess is greater (insulation class *A*)	1·0	0·8	0·8	0·8	1·0

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002
Telephones: 323 0131, 323 3375, 323 9402
Fax : 91 11 3234062, 91 11 3239399, 91 11 3239382

Telegrams : Manaksanstha
(Common to all Offices)

Central Laboratory:	Telephone
Plot No. 20/9, Site IV, Sahibabad Industrial Area, Sahibabad 201010	8-77 00 32
Regional Offices:	
Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002	323 76 17
*Eastern : 1/14 CIT Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	337 86 62
Northern : SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 38 43
Southern : C.I.T. Campus, IV Cross Road, CHENNAI 600113	235 23 15
†Western : Manakalaya, E9, Behind Marol Telephone Exchange, Andheri (East), MUMBAI 400093	832 92 95
Branch Offices:	
'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMEDABAD 380001	550 13 48
‡Peenya Industrial Area, 1st Stage, Bangalore-Tumkur Road, BANGALORE 560058	839 49 55
Gangotri Complex, 5th Floor, Bhadbhada Road, T.T. Nagar, BHOPAL 462003	55 40 21
Plot No. 62-63, Unit VI, Ganga Nagar, BHUBANESHWAR 751001	40 36 27
Kalaikathir Buildings, 670 Avinashi Road, COIMBATORE 641037	21 01 41
Plot No. 43, Sector 16 A, Mathura Road, FARIDABAD 121001	8-28 88 01
Savitri Complex, 116 G.T. Road, GHAZIABAD 201001	8-71 19 96
53/5 Ward No. 29, R.G. Barua Road, 5th By-lane, GUWAHATI 781003	54 11 37
5-8-56C, L.N. Gupta Marg, Nampally Station Road, HYDERABAD 500001	20 10 83
E-52, Chitaranjan Marg, C-Scheme, JAIPUR 302001	37 29 25
117/418 B, Sarvodaya Nagar, KANPUR 208005	21 68 76
Seth Bhawan, 2nd Floor, Behind Leela Cinema, Naval Kishore Road, LUCKNOW 226001	23 89 23
NIT Building, Second Floor, Gokulpat Market, NAGPUR 440010	52 51 71
Patliputra Industrial Estate, PATNA 800013	26 23 05
Institution of Engineers (India) Building 1332 Shivaji Nagar, PUNE 411005	32 36 35
T.C. No. 14/1421, University P.O. Palayam, THIRUVANANTHAPURAM 695034	6 21 17

---

*Sales Office is at 5 Chowringhee Approach, P.O. Princep Street, CALCUTTA 700072	27 10 85
†Sales Office is at Novelty Chambers, Grant Road, MUMBAI 400007	309 65 28
‡Sales Office is at 'F' Block, Unity Building, Narashimaraja Square, BANGALORE 560002	222 39 71

Printed at Simco Printing Press, Delhi